Determining Spin-Flavor Dependent Distributions

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Many of the present and planned polarization experiments are focusing on determination of the polarized glue. There is a comparable set of spin experiments which can help to extract information on the separate flavor-dependent polarized distributions. This talk will discuss possible sets of experiments, some of which are planned at BNL, CERN and DESY, which can be used to determine these distributions. Comments include the estimated degree to which these distributions can be accurately found.

Recent history of spin phenomenology

1980's and early 90's

Extraction of polarized distributions (mostly quarks) from data (PDIS)
Result: valence, up and down sea relatively determined but strange sea, glue and orbital angular momentum unknown

Mid-90's to present

Calculations/design of experiments to determine ΔG (RHIC, HERA, CERN)
Results: pending

Future extension

Calculations and design of experiments to determine flavor dependence of quark spin

Conventions and Constraints

1. Parton Distributions
   a. Factorization (Gauge Inv and Chiral Inv)
   b. Evolution (NLO DGLAP, $N_f = 3 \to 4$)
   c. Valence and sea
   $\Delta u(x,Q^2) = \Delta u_v(x,Q^2) + \Delta u_s(x,Q^2)$
   $\Delta d(x,Q^2) = \Delta d_v(x,Q^2) + \Delta d_s(x,Q^2)$

2. Sum Rules
   a. Bjorken Sum Rule

$$A_3 = \int_0^1 dx[g_1^p - g_1^n] = \langle[\Delta u_v - \Delta d_v]\rangle = g_A(1 - \alpha_s^{corr})$$

   b. Hyp. data

$$A_8 = \int_0^1 dx[\Delta u + \Delta d - 2\Delta s] = 0.58 \pm 0.02$$

   c. Anomaly Independent Relation:

$$A_0 = \int_0^1 dx[\Delta u+\Delta d+\Delta s] = 9(1-\alpha_s^{corr})^{-1}\langle g_1^p\rangle - \frac{3}{4}A_3 - \frac{1}{4}A_8$$

A_3, A_8: Anomaly terms cancel
$A_0 = \langle \Delta q\rangle_{tot} - \Gamma$

Valence models

1. Carlitz-Kaur: modified SU(6)

$$\begin{aligned}\Delta u_v &= \cos(\theta_d)(u_v - 2d_v/3) \\ \Delta d_v &= \cos(\theta_d)(-d_v/3)\end{aligned}$$

2. Isgur: hyperfine interactions CQM

$$\begin{aligned}\Delta u_v &= (1 - C_A)(u_v - 2d_v/3) \\ \Delta d_v &= (1 - C_A)(-d_v/3)\end{aligned}$$

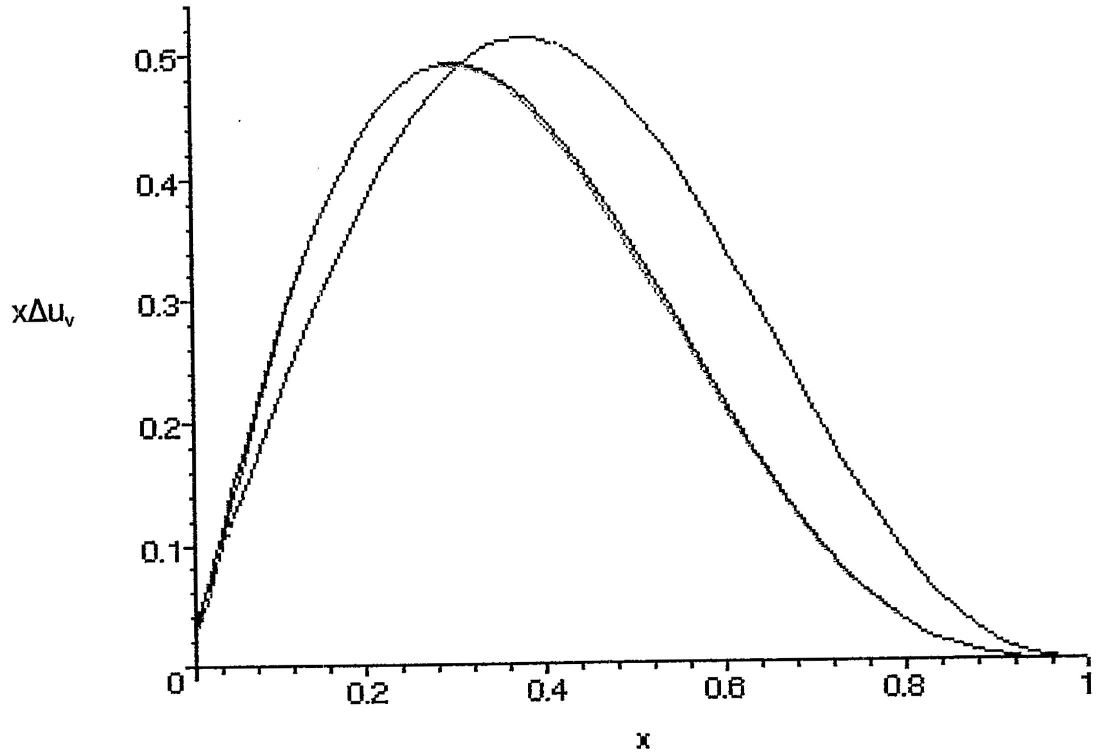
where $C_A = nx(1-x)^n$ for $2 \leq n \leq 4$.

3.Bourrely-Soffer: Pauli Exclusion/Statistical model

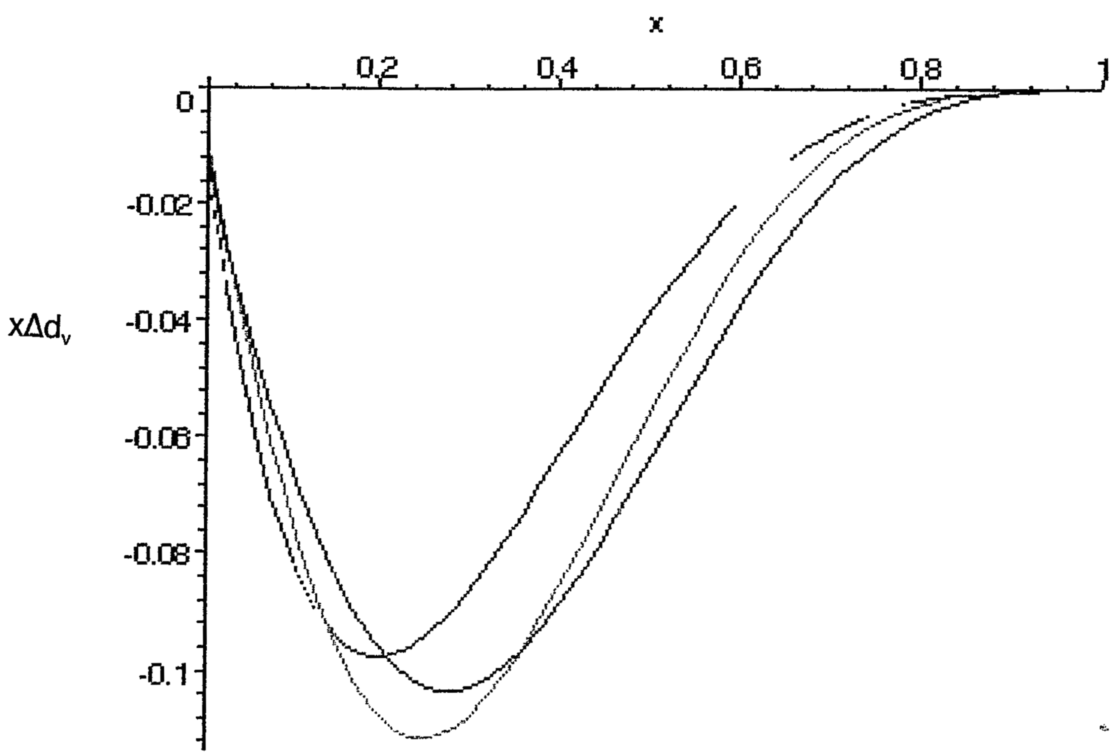
$$\begin{aligned}\Delta u_v &= u_v - d_v \\ \Delta d_v &= -d_v/3\end{aligned}$$

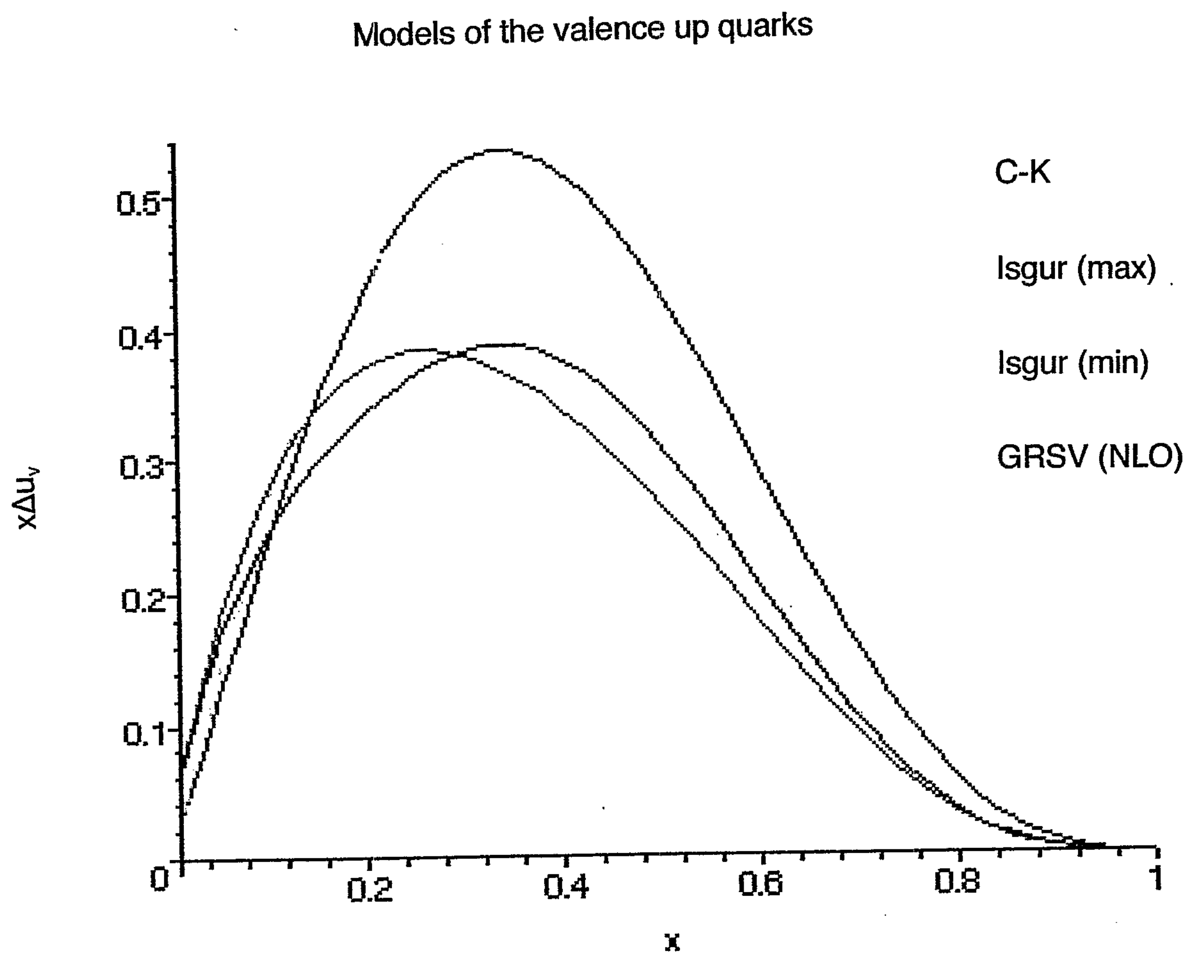
4. Bartelski, Tatur and LSS: NLO fits to data
Parametrize Δu_v and Δd_v

$x\Delta u_v$ for different unpolarized distributions

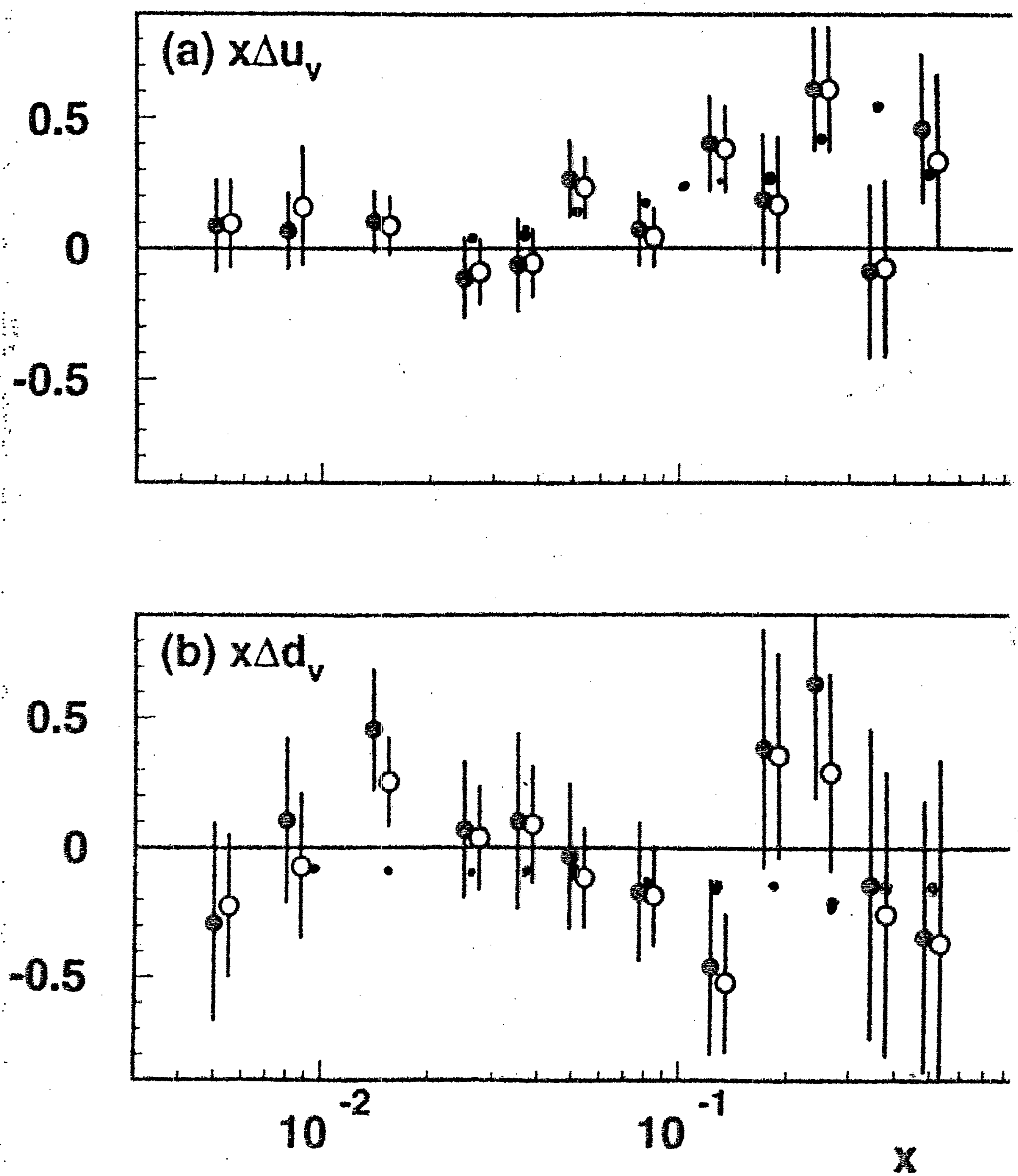


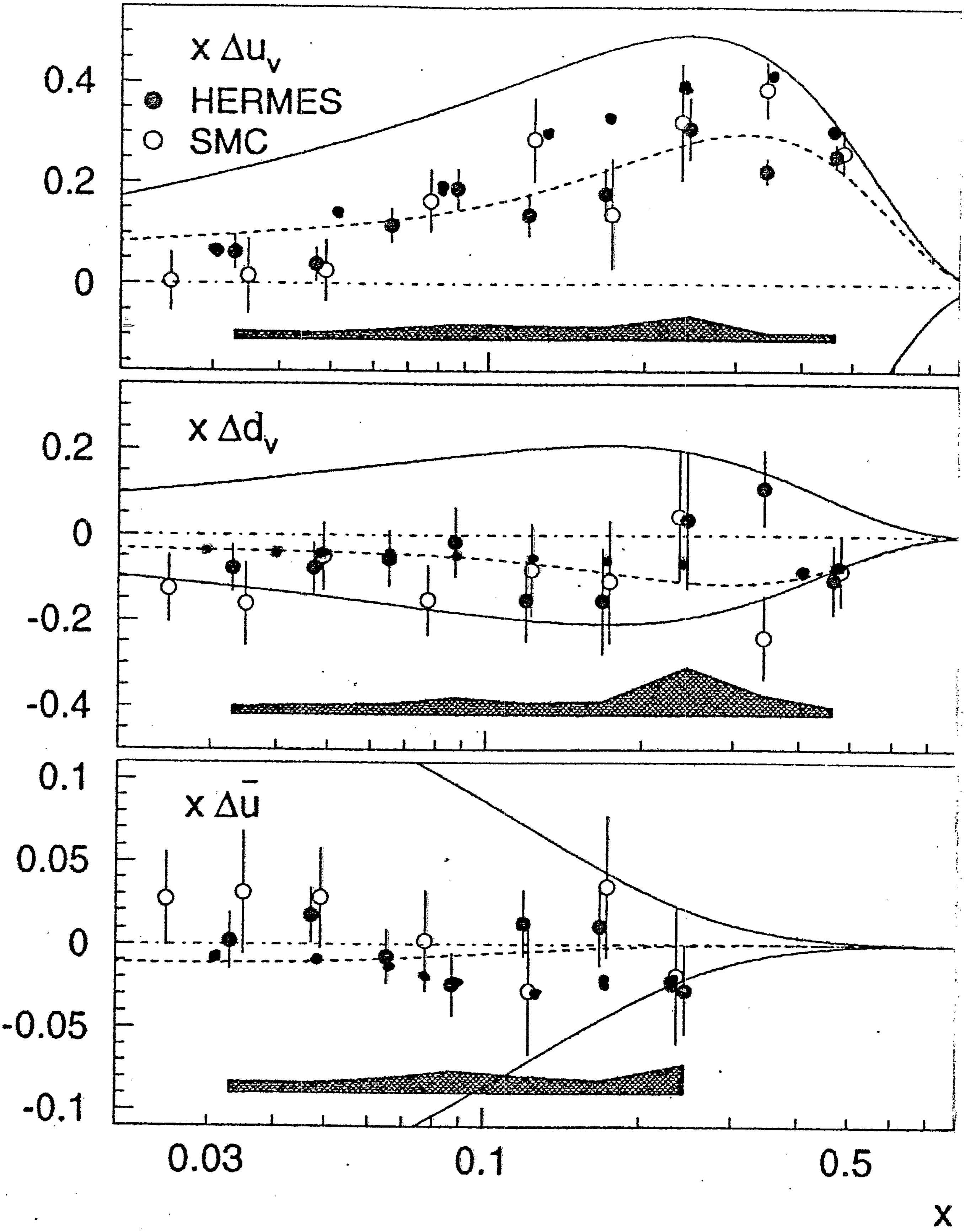
$x\Delta d_v$ for different unpolarized distributions




Models of the valence up quarks
C-K
Isgur (max)
Isgur (min)
GRSV (NLO)
$x\Delta u_v$
0.5
0.4
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1
x

SMC





x Δu_v
HERMES
SMC
x Δd_v
x Δū
0.4
0.2
0
-0.2
-0.4
0.1
0.05
-0.05
-0.1
0.03
0.1
0.5
x

Sea models

A. Theoretical w/ NVL TP

1. Pauli Exclusion
Thermodynamic model combines Pauli exclusion, F_2 data and axial vector couplings, F and D

2. Light-cone M-B fluctuations
Intrinsic $q\bar{q}$ with valence in energetically favored state, coupling to virtual $K^+\Lambda$ is source of intrinsic $s\bar{s}$ and excess $d\bar{d}$ over $u\bar{u}$ comes from flux $p \to \pi + n$

3. Chiral quark model
Sea determined by Chiral flux of valence, creating GB, such that $\Delta\bar{q} = 0$ all flavors, similar to instanton-spin non-flip is suppressed

4. Meson cloud model
PS mesons replace GB in chiral model

Model	Δu	$\Delta \bar{u}$	Δd	$\Delta \bar{d}$	Δs	$\Delta \bar{s}$	Δc	$\Delta \bar{c}$
Thermo	$\bar{u} - \bar{d}$	$\bar{u} - \bar{d}$	0	0	0	0	0	0
L-Cone	–	–	< 0	0	< 0	0	0	0
χQM	0.83	0	-0.39	0	-0.07	0	-0.02	0
M-cloud	Δu	0	0	Δu	–	–	0	0
CQSM	–	$\Delta \bar{d} - Cx^{\alpha}(\bar{d} - \bar{u})$	–	see $\Delta \bar{u}$	0	0	0	0

5. Chiral quark-soliton model
Quark fields interact w/ massless π's

6. Lattice calculations
Moments of up and down Valence and Sea

B. Phenomenological

1. Gluon splitting (GGR, BT)
Sea created by gluons with flavor asymmetry due to unpol. distrs. - parametrization from A-V constraints and PDIS data

2. Direct data fits (LSS, BT)
SU(3) sea with some breaking (s)

3. LO/NLO moment fits (BB)
MRST-type parametrization with corresponding errors included

Sea models

4. Fragmentation functions (MY)
Uses SI-DIS data and MRST/GRV unpol. distrs. to extract $\Delta\bar{d} - \Delta\bar{u} = -x^{0.18}(\bar{d}-\bar{u})$

5. Heavy quark contributions
χQM: $\Delta c \approx -0.003$ and $\Delta\bar{c} = 0$
Instanton: From $\Delta c = -0.012 \pm 0.002$ to $\Delta c = -0.020 \pm 0.005$
OPE and Axial anomaly: $\Delta c = -0.0024 \pm 0.0035$
Thus, Δc is at most 5% of the total polarized sea, and likely less

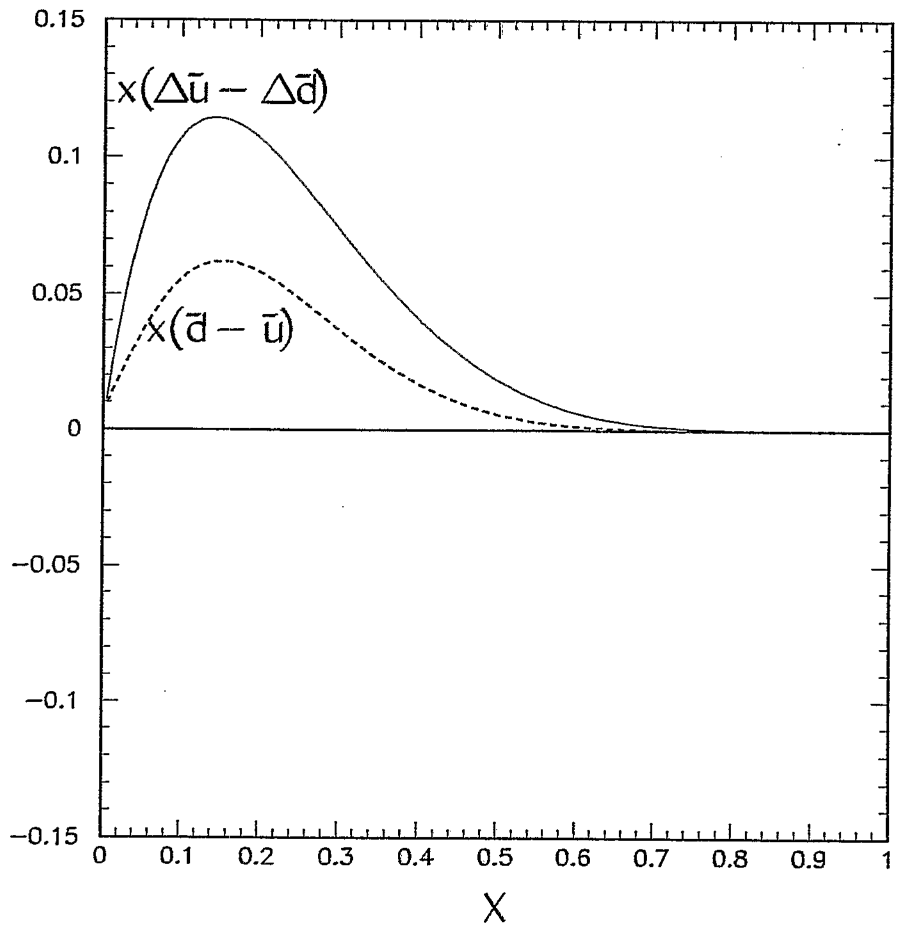


Figure 7: $x(\Delta\bar{u} - \Delta\bar{d})$ at $Q^2 = 0.36$ GeV^2 predicted by the chiral-quark soliton model is shown as the solid curve. The GRV94 LO parametrization of $x(\bar{d} - \bar{u})$ at $Q^2 = 0.4$ GeV^2 is shown as the dashed curve.

Experiments

Valence

1. Asymmetries in pion production

$$\Delta A^{\pi} \equiv A_p^{\pi^+} - A_p^{\pi^-} = \frac{4\Delta u_v - \Delta d_v}{4u_v - d_v}$$

Asymmetries differ by 0.2 for $x < 0.5$ and by 0.1 for $0.5 \leq x \leq 0.9$

Nxt TP

2. Differences in pion production for p and $\bar{p}$

$$A_{LL}^{DV}(\pi^0) \equiv \frac{a_{LL}d\sigma(p\bar{p} \to \pi^0 + X) - a_{LL}d\sigma(pp \to \pi^0 + X)}{d\sigma(p\bar{p} \to \pi^0 + X) - d\sigma(pp \to \pi^0 + X)}$$

Large asymmetries for $0.1 \leq p_T/\sqrt(s) \leq 0.3$ but high energy $\bar{p}$ beams are difficult to do

Using the parton model and neglecting the intrinsic quark momentum, one can derive th following expressions for the hadron asymmetries

$$A_p^h = \frac{1}{P_B P_T f D} \cdot \frac{N^{\uparrow\downarrow} - N^{\uparrow\uparrow}}{N^{\uparrow\downarrow} + N^{\uparrow\uparrow}} \tag{A.1}$$

on a proton target, for $h = \pi^+, \pi^-, \mathrm{K}^+$ and K^-.

$$\begin{aligned}
A_\mathrm{p}^{\pi^+} &= \frac{4D_1\Delta u_v + D_2\Delta d_v + 4(D_1+D_2)\Delta\bar{u} + (D_1+D_2)\Delta\bar{d} + 2D_2\Delta\bar{s}}{4D_1 u_v + D_2 d_v + 4(D_1+D_2)\bar{u} + (D_1+D_2)\bar{d} + 2D_2\bar{s}}, \\
A_\mathrm{p}^{\pi^-} &= \frac{4D_2\Delta u_v + D_1\Delta d_v + 4(D_1+D_2)\Delta\bar{u} + (D_1+D_2)\Delta\bar{d} + 2D_2\Delta\bar{s}}{4D_2 u_v + D_1 d_v + 4(D_1+D_2)\bar{u} + (D_1+D_2)\bar{d} + 2D_2\bar{s}}, \\
A_\mathrm{p}^{\mathrm{K}^+} &= \frac{4D_3\Delta u_v + D_4\Delta d_v + 4(D_3+D_4)\Delta\bar{u} + 2D_4\Delta\bar{d} + (D_1+D_4)\Delta\bar{s}}{4D_3 u_v + D_4 d_v + 4(D_3+D_4)\bar{u} + 2D_4\bar{d} + (D_1+D_4)\bar{s}}, \\
A_\mathrm{p}^{\mathrm{K}^-} &= \frac{4D_4\Delta u_v + D_4\Delta d_v + 4(D_3+D_4)\Delta\bar{u} + 2D_4\Delta\bar{d} + (D_1+D_4)\Delta\bar{s}}{4D_4 u_v + D_4 d_v + 4(D_3+D_4)\bar{u} + 2D_4\bar{d} + (D_1+D_4)\bar{s}},
\end{aligned} \tag{A.2}$$

where u_v and d_v denote the valence quark distributions, $q_v = q - \bar{q}$.

The corresponding formulae for the deuteron are

$$\begin{aligned}
A_\mathrm{d}^{\pi^+} &= \frac{(4D_1+D_2)(\Delta u_v + \Delta d_v) + 5(D_1+D_2)(\Delta\bar{u} + \Delta\bar{d}) + 4D_2\Delta\bar{s}}{(4D_1+D_2)(u_v + d_v) + 5(D_1+D_2)(\bar{u} + \bar{d}) + 4D_2\bar{s}}, \\
A_\mathrm{d}^{\pi^-} &= \frac{(D_1+4D_2)(\Delta u_v + \Delta d_v) + 5(D_1+D_2)(\Delta\bar{u} + \Delta\bar{d}) + 4D_2\Delta\bar{s}}{(D_1+4D_2)(u_v + d_v) + 5(D_1+D_2)(\bar{u} + \bar{d}) + 4D_2\bar{s}}, \\
A_\mathrm{d}^{\mathrm{K}^+} &= \frac{(4D_3+D_4)(\Delta u_v + \Delta d_v) + 2(2D_3+3D_4)(\Delta\bar{u} + \Delta\bar{d}) + 2(D_1+D_4)\Delta\bar{s}}{(4D_3+D_4)(u_v + d_v) + 2(2D_3+3D_4)(\bar{u} + \bar{d}) + 2(D_1+D_4)\bar{s}}, \\
A_\mathrm{d}^{\mathrm{K}^-} &= \frac{5D_4(\Delta u_v + \Delta d_v) + 2(2D_3+3D_4)(\Delta\bar{u} + \Delta\bar{d}) + 2(D_1+D_4)\Delta\bar{s}}{5D_4(u_v + d_v) + 2(2D_3+3D_4)(\bar{u} + \bar{d}) + 2(D_1+D_4)\bar{s}},
\end{aligned}$$

$$\begin{aligned}
A_\mathrm{p}^{\pi^+-\pi^-} &= \frac{4\Delta u_v - \Delta d_v}{4u_v - d_v}, \\
A_\mathrm{p}^{\mathrm{K}^+-\mathrm{K}^-} &= \frac{\Delta u_v}{u_v}, \\
A_\mathrm{d}^{\pi^+-\pi^-} &= \frac{\Delta u_v + \Delta d_v}{u_v + d_v}, \\
A_\mathrm{d}^{\mathrm{K}^+-\mathrm{K}^-} &= A_\mathrm{d}^{\pi^+-\pi^-}.
\end{aligned}$$

Valence and Sea

1. PV SSA in W production ($A_L^{W^\pm}$)

$$A_L^{W^+}(y) = \frac{\Delta u(x_a)\bar{d}(x_b) - \Delta\bar{d}(x_a)u(x_b)}{u(x_a)\bar{d}(x_b) + \bar{d}(x_a)u(x_b)}$$

$$A_L^{W^-}(y) = \frac{\Delta d(x_a)\bar{u}(x_b) - \Delta\bar{u}(x_a)d(x_b)}{d(x_a)\bar{u}(x_b) + \bar{u}(x_a)d(x_b)}$$

At $y = 0$, $x \approx M_W/\sqrt(s)$

$$A_L^{W^+} \sim \frac{1}{2}(\frac{\Delta u}{u} - \frac{\Delta\bar{d}}{\bar{d}})$$

$$A_L^{W^-} \sim \frac{1}{2}(\frac{\Delta d}{d} - \frac{\Delta\bar{u}}{\bar{u}})$$

At $y = -1$, x small

$$A_L^{W^+} \sim -\frac{\Delta\bar{d}}{\bar{d}})$$

$$A_L^{W^-} \sim -\frac{\Delta\bar{u}}{\bar{u}})$$

At $y = +1$, x moderate

$$A_L^{W^+} \sim \frac{\Delta u}{u}$$

$$A_L^{W^-} \sim \frac{\Delta d}{d}$$

Limited kinematic range with RHIC

2. PC DSA in Z production ($A_{LL}^{Z^0}$)

$$A_{LL}^{Z^0}(y) \sim \Sigma_i \frac{\Delta q_i(x_a)\Delta \bar{q}_i(x_b) + \Delta \bar{q}_i(x_a)\Delta q_i(x_b)}{q_i(x_a)\bar{q}_i(x_b) + \bar{q}_i(x_a)q_i(x_b)}$$

Predicted asymmetries of ~ 0.1 for $\sqrt{(s)} = 500$ GeV
Good test of chiral QM and instanton models

Sea

1. CC interactions: g_5 (HERA)

$$A^{W^\pm} = \frac{\mp 2b g_1^{W^\pm} + a g_5^{W^\pm}}{a F_1^{W^\pm} \mp b F_3^{W^\pm}}$$

In HERA kinematic range: $a \gg b$ so g_5/F_1 is probed

$$\begin{aligned} g_5^{W^-} &= \Delta u + \Delta \bar{d} + \Delta \bar{s} + \Delta c \\ g_5^{W^+} &= \Delta \bar{u} + \Delta d + \Delta s + \Delta \bar{c} \end{aligned}$$

Problems with uncertainties in hadronic energy scale of calorimeter - larger than asymmetries
Difficult at RHIC too

2. CC interactions: g_1 in pol. $e^\pm p \to \nu(\bar{\nu})X$ (HERA)

$$\begin{aligned} g_1^{\nu p} &\sim \Delta \bar{u} + \Delta d + \Delta s + \Delta \bar{c} \\ g_1^{\bar{\nu} p} &\sim \Delta u + \Delta \bar{d} + \Delta \bar{s} + \Delta c \end{aligned}$$

Difference is proportional to valence (NS)

Experiments: Sea

3. SI-PDIS (NLO) extraction of $\Delta\bar{u} - \Delta\bar{d}$ from data

4. Measurement of $\Delta(q+\bar{q})/(q+\bar{q})$ at HERA

5. PV measurement of g_3 in ν scattering (p and n) JHF

$$\frac{1}{2}(g_3^{\nu(p+n)} - g_3^{\bar{\nu}(p+n)} \sim \Delta s + \Delta\bar{s} - \Delta c - \Delta\bar{c}$$

Since g_3 comes from $W_{\mu\nu}^{\perp}$, which is small
this may be difficult to distingish

6. Polarized DY at RHIC (50-100 GeV)
or JHF (50 GeV)
Moderately sized asymmetries for smaller $\sqrt(s)$
Cross sections decrease, so larger $\sqrt(s)$ not feasible
RHIC luminosity low at 50 GeV (injection energy) but
higher at 100 GeV.
Polarized beams at JHF are suitable for DY
Good for size of sea, but not distinguishing flavor
dependence $(\Delta q, \Delta\bar{q})$
DY $\frac{\sigma(pd)}{\sigma(pp)} \sim \frac{\Delta\bar{d}}{\Delta\bar{u}}$

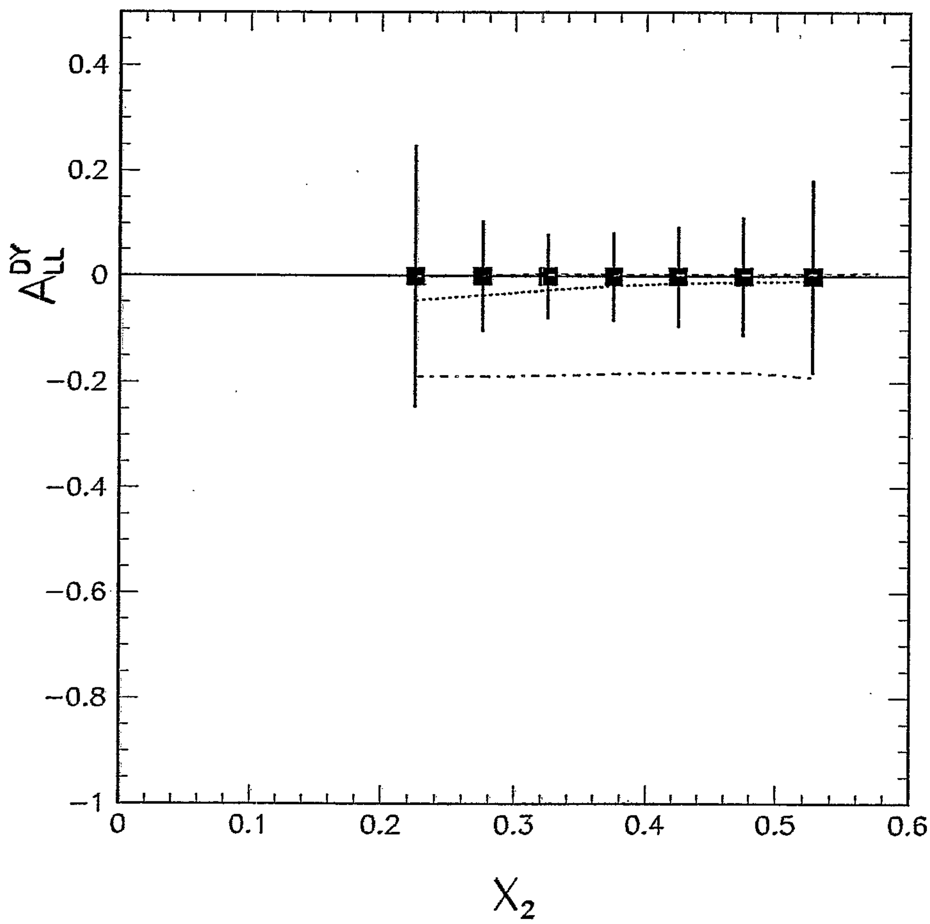


Figure 8: Expected statistical accuracy for measuring the double-helicity asymmetry A_{LL}^{DY} in polarized $p+p$ Drell-Yan at the 50-GeV PS for a 120-day run. The dashed, dotted, and dash-dotted curves correspond to calculations using polarized PDF parametrization of G-S (set A, set C) and GRSV, respectively.

Conclusions

1. Considerable progress in Δq_v, Δu_{tot} and Δd_{tot}

2. Theoretical predictions for valence, sea quark and antiquark flavors

3. Suggested experiments include most possibilities for four flavors, which could distinguish all separations

4. Many of the suggested measurements are not feasible

5. Those which are feasible should be done

6. Opens possibilities for RHIC, HERA, COMPASS and JHF